Use of a Hot-Wire Flow Meter in the Study of Laryngeal Function

Kitajima, Kazutomo; Isshiki, Nobuhiko; Tanabe, Masahiro

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Aerodynamic aspect of the laryngeal function have been studied by many peoples. The method which is hoped for this study is to have a data right at the glottis without any supraglottic intervention. Application of the inverse filter which is calculated theoretically may remove the supraglottic effect. This method, however, require some troublesome procedures. It is not practical at least for clinical use. In 1975 Sondhi has devised a reflectionless tube which is proved to be useful to get a glottal waveform(1). The rationale of this method is that the effect of vocal tract resonances on the glottal waveform is considerably reduced by phonating into a reflectionless uniform tube. The details of clinical application of this method is reported elsewhere(2). A pneumotachograph which has been used in voice study for many years has a frequency response of less than 50 Hz. Therefore this is not useful for a purpose to obtain a information of each cycle or glottal wave. A hot-wire flow meter of recent years has a excellent frequency response. It seems reasonable to try this flow meter for obtaining a glottal waveform.

A hot-wire flow meter has been used for gas flow measurement in many fields. It is based on King's low, accoding to which heat removed from a hot-wire by a gas stream is linearly related to the square root of the velocity of the gas stream. The old type, however, has too low frequency response to be used for voice study. The new type on the other hand, is of a constant-temperature type(3). It has a differential amplifier that detects any change in the resistance of the hot-wire and instantaneously feeds back a voltage to maintain the temperature of the hot-wire at constant value. The frequency response of this type is flat up to 5 KHz. In this paper clinical application of a hot-wire flow meter is reported.

If the glottal wave is idealized to be a triangular wave and the glottal area function is supporsed to be equal to the glottal volume velocity function (see figure 1), the rms (root mean square) value of the AC

Kazutomo KITAJIMA (北嶋和智), Nobuhiko ISSHIKI (一色信彦), Masahiro TANABE (田辺正博): Voice Science Laboratory, Departments of Otolaryngology and Plastic Surgery, School of Medicine, Kyoto University.

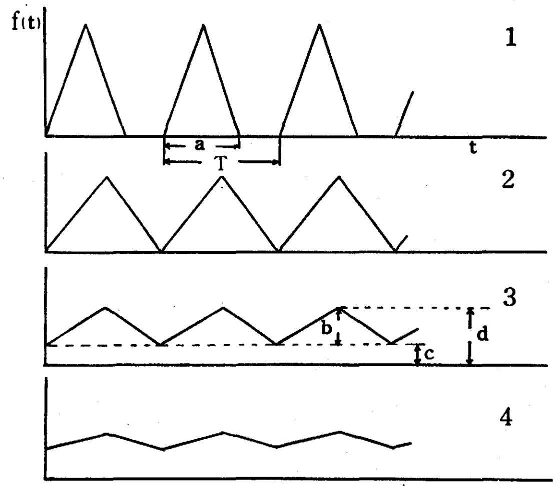

Figure 1. Four idealized triangular waves are shown. The waves 1 and 2 are normal phonation. The waves 3 and 4 are correspond to the phonation with constant leakage of air in case of hoarse voice.
T=fundamental period. a=period during which the glottis is open. b=d-c (indicative of amplitude of vibration). c=minimal glottal area in vibratory cycle. d=peak value (maximal glottal area in vibratory cycle).

component of the glottal wave can be defined as follows.

the rms of AC component of

$$\text{the glottal wave} = \frac{K}{\sqrt{3} \cdot T}$$

T=fundamental period

$$K = \frac{1-X}{1+X}, \quad X = \frac{\text{minimal glottal width } (=c \text{ in fig. } 1)}{\text{maximal glottal width } (=d \text{ in fig. } 1)}$$

If the efficiency of voice can be defined as the ratio of the rms of AC to the mean volume velocity (=DC component), this efficiency can be expressed as follows.

efficiency of voice=rms of AC / mean volume velocity(DC)

$$= \frac{K}{\sqrt{3} \cdot T} \Big/ \frac{1}{T}$$

$$= \frac{K}{\sqrt{3}}$$

Based upon these formulae, the efficiency value of wave 2 in figure 1 is proved to be about 0. 5. Wave 3 and wave 4 show the values lower than 0. 5. It is concluded from the idealized models in figure 1 that when the efficiency value is lower than 0. 5, constant air leakage through the glottis is observed, in another word, glottal closure is not complete. The details were already reported elsewhere[4].

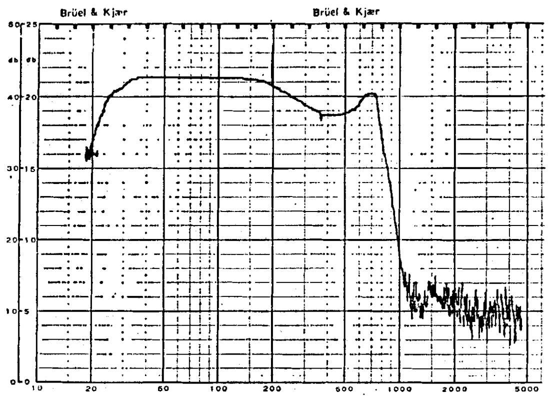

Figure 2. The frequency responce of the hot-wire flow meter. Note that the responce curve is quasi-flat up to 750 Hz.

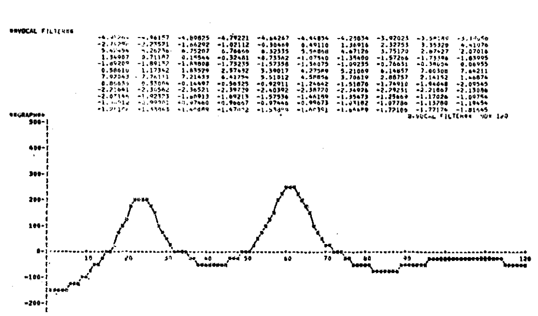

Figure 3. The transmission characteristic including the vocal tract and the tube of the flow meter. Two peaks can be noticed around 230 Hz and 600 Hz.

The frequency response of the hot-wire flow meter which is used in this study is shown in figure 2. It is noted that the response curve is quasi-flat up to 750 Hz. (The frequency responce of the hot-wire flow meter is defined depending upon the size of silver wire. It can be expanded up to 5 KHz). The transmission characteristic including the vocal tract and the tube of flow meter is not flat as is shown in figure 3. Two peaks are noticed around 230 Hz and 600 Hz. Therefore it should be in mind that the glottal waveform in approximation is obtained with the hot-wire flow meter.

The output waves of the flow meter used in normal and pathologic larynges are shown in figure 4 and 5. Sustained neutral vowels were uttered through the mouthpiece of flow meter. Figure 4 shows a wave of normal subject. It is noticed that the bottom of each cycle is zero. This means that the glottal closure during phonation is complete. On the other hand, in figure 5, the bottom of each cycle is not zero. It is reasonable to say that the air is leaking through the glottis. This is the case of the

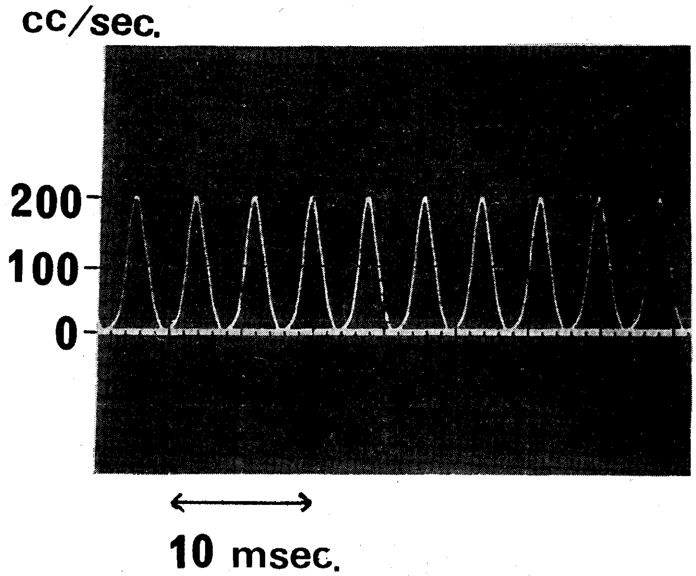

Figure 4. The output of the hot-wire flow meter in normal phonation. It is noted that the bottom of each cycle reachs zero, indicating that the glottal closure is complete.

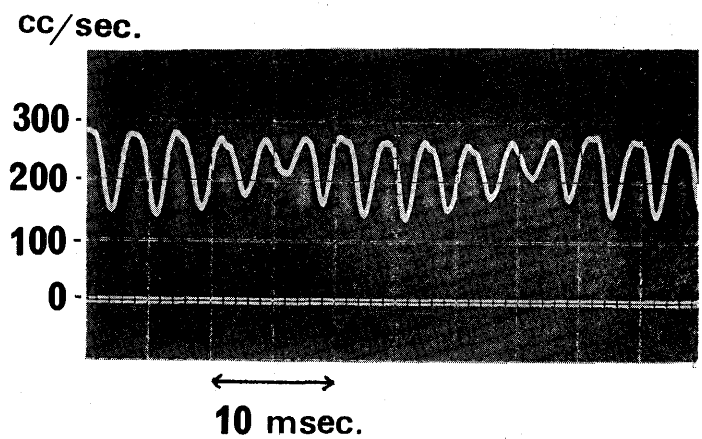

Figure 5. The output of the hot-wire flow meter in pathologic larynx. It is noted that the bottom of each cycle does not reach zero, indicating the leakage of air through the glottis.

recurrent laryngeal nerve paralysis which shows large glottal gap during phonation.

It is interesting to note that there is a quite well approximation between the output wave of the flow meter and the triangular model shown in figure 1. Therefore it is thonght that the formula of efficiency described calier can be applied to the output wave of the flow meter.

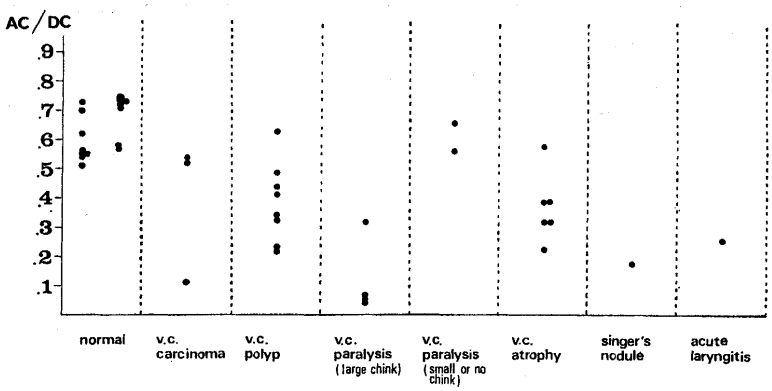

Figure 6. The values of the efficiency of voice (AC/DC) in 20 normal and 25 pathologic larynges. It is noted that the normal subjects do not show the values lower than 0.5. On the other hand, pathologic ones do not show the values higher than 0.5 except several cases.

In twenty normal and twenty-five pathologic larynges, the value of efficiency (AC/DC) are calculated for each case. Pathologic larynges include vocal cord (v. c.) carcinoma, v. c. polyp, v. c. paralysis, v. c. atrophy, singer's nodule and acute laryngitis. It is quite interesting to note that the normal subjects do not show the values lower than 0.5. On the other hand, the pathologic ones do not show the value higher than 0.5 except several cases. This finding agrees well with the calculation based upon the idealized model.

Although the problem of the transmission characteristic mentioned ealier has not been solved, the aerodynamic study with hot-wire flow meter could provide a useful information about the glottal function.

SUMMARY

Hot-wire flow meter was used to obtain the glottal waveform. The output of the flow meter showed a good approximation to the glotal wave form.

When the efficiency of voice was defined as the ratio of rms (root mean square) of AC component in the output wave to DC component (mean volume velocity) in it, 0.5 was the critical efficiency value which is separating the normal and pathologic aryngles. Normal subjects always showed the values higher than 0.5.

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